COLORADO
DEPARTMENT OF NATURAL RESOURCES

ROCK TALK

Division of Minerals and Geology
Colorado Geological Survey

Volume 5 Number 2 April 2002

We Don't Have Earthquakes in Colorado, Do We?

This is a typical response when a CGS scientist tells someone that he or she is engaged in earthquake hazard research. Following the recent magnitude 6.8 earthquake in Seattle, media reporters in Denver asked, "Could it happen here?" They were surprised to learn that an earthquake that strong has already occurred in Colorado.

In a recent six-month period, four earthquakes between Magnitude 4.0 and 4.6 struck Colorado. One of these caused minor damage to homes and businesses in southern Colorado. Denver experienced an earthquake in the 1960s that caused a million dollars in damage and threw a CGS geologist out of her bed when she was nine years old. CGS' award-winning CD-ROM, *Colorado Earthquake Information, 1867–1996*, lists nearly 500 earthquakes in Colorado since 1867 (Figure 1). The Federal Emergency Management Agency (FEMA) recently released a report that estimates Colorado will suffer $5.8 million in annualized losses from earthquakes.

Yet, very few people in Colorado are aware of these facts and fewer still are preparing for the possibility of a damaging earthquake. The Colorado Geological Survey is conducting research to try and better understand the earthquake hazard. We are also trying to help the people of Colorado become more aware of and, in cooperation with Colorado's Office of Emergency Management (OEM), prepared for a strong earthquake in Colorado.

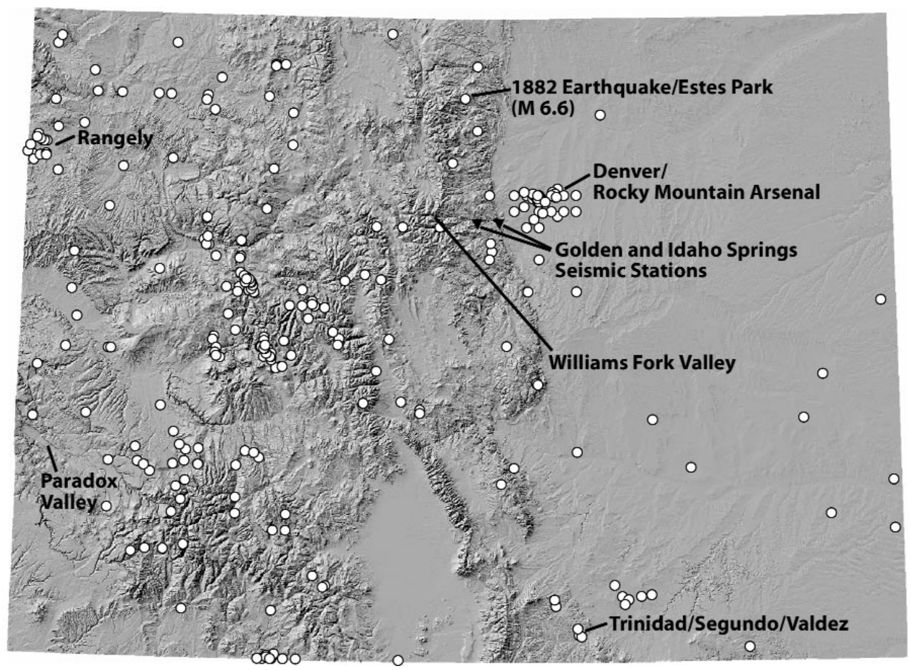

Figure 1. *Historical earthquake activity in Colorado, 1867–1996. Locations discussed in this* RockTalk *are labeled.* MODIFIED FROM KIRKHAM AND ROGERS, 2000

What Causes Earthquakes?

Earthquakes are simply the vibrations created when large blocks of Earth's crust move with respect to one another. The break between these blocks is a fault. Virtually all earthquakes in Earth's crust occur from movement on faults. Commonly the fault can be recognized at the surface. However, some faults are buried and do not reach the surface. The recent earthquake swarm west of Trinidad illustrates the relationship of earthquakes to faulting (Figure 2).

When strong earthquakes (usually greater than magnitude 6.5) occur,

field notes from the director

Geoscientists in many places have struggled with the difficult problem of how to raise awareness of the possibility of a strong earthquake in an area, without alarming people. CGS also faces this problem. Colorado is similar to several other states that have a history of strong earthquakes in the recent geologic past, but not enough information to say when or where the next big one will strike. We know enough about the earthquake risk in Colorado to know that we need to know a lot more.

In the first place there have been far fewer research efforts to understand the earthquake hazard in Colorado than in many other states such as Utah, New Mexico, Tennessee, and South Carolina. The data are too scattered and the research too insufficient to lead to strong conclusions, but the research that has been done in Colorado alerts us to the need to know much more. Secondly, even in a place like California, where an abundance of data are available and reasonably well understood, it is still not possible to predict earthquake activity. Finally, individuals and organizations who do earthquake research must be extremely careful about how to share their results with others. They must carefully balance full disclosure about earthquake information with the danger of causing panic by over-emphasizing the potential for damage.

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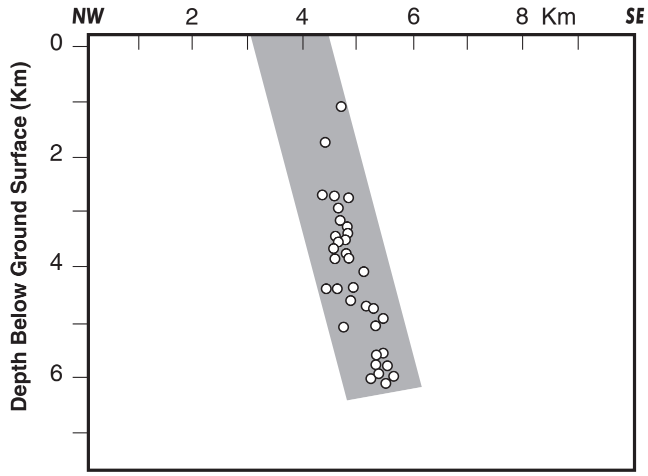

***Figure 2**. A cross section of the 2001 Trinidad earthquakes showing that they define a fault plane dipping about 70° to the southeast. CGS geologists mapped a northeast-trending fault where the gray zone intersects the surface also dipping 70° to the southeast. Thus, the surface topography and geology, the spatial distribution of the earthquakes, the first motion solutions of the earthquakes, as well as seismic and subsurface data all agree that the earthquakes are occurring along this fault plane.* MODIFIED FROM MEREMONTE AND OTHERS, 2002

they commonly rupture the surface. Therefore, when geologists see that a particular fault has broken the surface in the recent past, we can be fairly certain that it was the result of a strong earthquake.

Because earthquakes are a result of movements on faults, and because the same faults tend to move repeatedly, it is important to identify and study faults in Colorado that have moved in the recent geologic past (Figure 3).

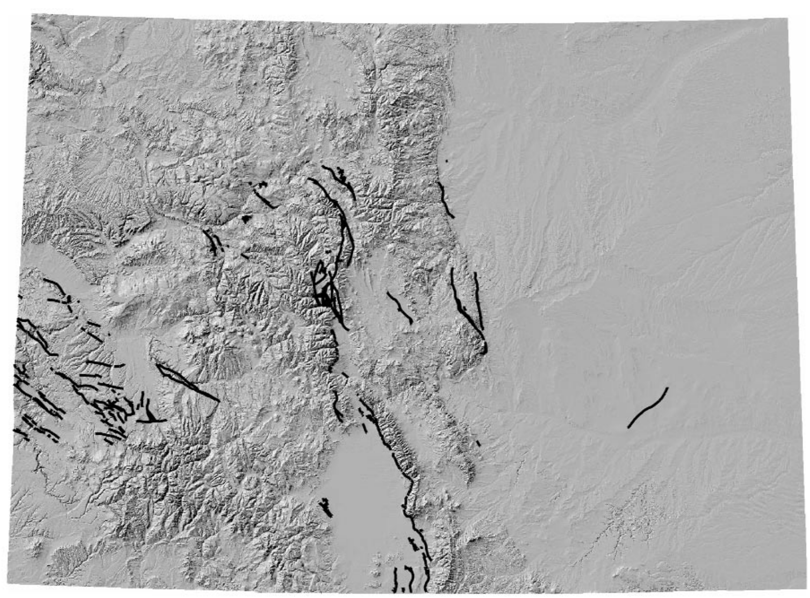

***Figure 3**. Map showing distribution of known Quaternary faults (black lines) in Colorado. Quaternary faults are those faults that have moved in the most recent geologic period and thus should be carefully studied for recurrence intervals of strong earthquakes.* MODIFIED FROM WIDMANN AND OTHERS, 1998

Studying past activity helps us understand the potential for future strong earthquakes. The principal objectives of fault studies is to study past earthquakes in order to determine how strong they were and how often they recur.

How Do We Measure the Size of an Earthquake? (Magnitude, Intensity, and Strong Motion)

The strength of an earthquake may be measured in terms of its magnitude, intensity, and strong motion. Each of these measurements of an earthquake is useful in its own right.

Magnitude (M)

Magnitude (M) is "the scientists' measure" and is the most common, but one of the most confusing, measures of an earthquake's size. The fascinating and informative book, *Magnitude 8* (Fradkin, 1998), ironically never uses the term "magnitude" in the main body of the book. The author asserts at the end of the book, "The concept of magnitude is a good example of the inability of the vast majority of seismologists to communicate adequately with the general public." Confusion is increased because there is Richter magnitude (M_L), teleseismic body wave magnitude (m_b), duration magnitude (m_d), surface wave magnitude (M_s), and moment magnitude (M_W or simply M). Moment magnitude is the preferred characterization currently in use. The maximum moment magnitude calculated for a Colorado earthquake occurring since 1867 is M_W 6.6 (± 0.6). Only 14 states have experienced an earthquake larger than M 6.0.

Magnitude is a standardized measure of the total energy released in an earthquake as determined from seismographs around the world. A seismologist in India should be able to calculate the same magnitude for a given earthquake in California as a seismologist in Paris. The magnitude scale is logarithmic which means that a magnitude 6.0 earthquake is not just a little bit bigger than a magnitude 5.0, but would deflect the needle of the seismograph ten times more and release 30 times the stored-up seismic strain energy of a magnitude 5.0 earthquake. Likewise, a magnitude 7.0 releases 900 times (30 X 30) the energy of a magnitude 5.0 earthquake!

However, this does not mean that the strength of the shaking at any one spot is 30 times as great in a magnitude 8.0 as in a 7.0. It seems that once the ground is broken in a strong earthquake, a maximum intensity of shaking is reached. On the other hand, a magnitude 8.0 earthquake will generally have a longer fault break than a 7.0 and affect a wider area with strong shaking, and the shaking may go on longer. Therefore, the total energy release is greater, even though the strength of the shaking at any one instant, in any one place may be the same in both an 8.0 and a 7.0.

The length of time the ground shakes is important because it may trigger collapse of damaged buildings. It is analogous to bending a paper clip. One bend and it doesn't break. Bend it enough times and it finally breaks. That is why smaller aftershocks can be straws that break the camel's back. A building damaged by a big quake may be felled by smaller aftershocks.

Intensity

Intensity is "the people's measure" of an earthquake. Intensity is determined from descriptions of the shaking and damage experienced by people in various places surrounding the location of an earthquake. The most common descriptive tool is the Modified Mercalli Intensity Scale. It uses such descriptions as "books moved" or "books fell over" — the second describing a stronger intensity. The scale ranges from Intensity I (not felt) to Intensity XII (damage total). Intensity generally varies with the strength of the earthquake, the distance from the fault, the height of a building, and the type of soil the building is sitting on. Maps that show the distribu-

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tion of the various intensities for an earthquake are useful and help to determine where older earthquakes occurred and to convert them into modern magnitude scales. Intensity VII is the maximum experienced in Colorado during the past 135 years (Figure 4).

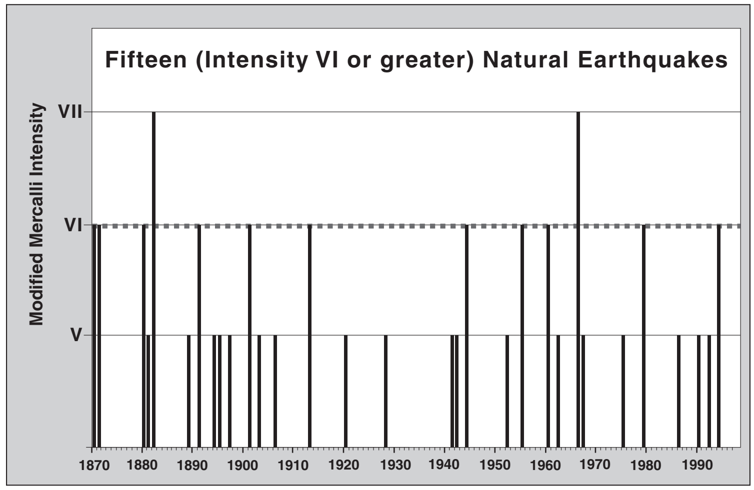

Figure 4. *Chart showing the occurrence of naturally-occurring earthquakes that exceeded Modified Mercalli Intensity V in Colorado from 1870–1996. Intensity VI includes such effects as: people have trouble walking, objects fall from shelves, pictures fall off walls, furniture moves, plaster in walls might crack, and trees and bushes shake.* DATA FROM KIRKHAM AND ROGERS, 2000

Strong Ground Motion

Ground motion is "the engineers' measure" of an earthquake's size. Special instruments called accelerographs measure the movement of the ground at a particular site or in a particular building, in terms of a percentage of the force of gravity (g). The ground normally experiences strong horizontal movement in an earthquake, but it can also move vertically. A measurement of a 1.0g vertical acceleration means that anything not strapped down, no matter how heavy, could be thrown into the air. Vertical acceleration greater than 1.0g was actually measured in a California earthquake.

Engineers are interested in three parameters of earthquake motion: the amplitude, the frequency content, and the duration of the motion. These measurements are useful in creating better design parameters for earthquake-resistant building codes.

Colorado's Strongest Earthquake

The strongest earthquake in Colorado during the past century and a half was M 6.6. This 1882 earthquake frightened people in Denver and other northern Front Range cities. It was so strong that the bolts holding the electric generators for Denver were snapped off and power was knocked out. The location of the earthquake was uncertain for over a century. However, careful research by CGS scientists in 1986 determined that the earthquake was centered about ten miles north of Estes Park (Kirkham and Rogers, 1986). Research by USGS scientists in 1996 confirmed this conclusion (Spence, and others, 1996).

Evidence of stronger earthquakes can be determined from recent geologic deposits. Study of deposits in Colorado show that magnitude 7.0 or higher earthquakes occurred on several faults since humans have lived in the area.

The Problem of Locating Earthquakes in Colorado

Earthquakes are located by triangulating between three or more seismograph stations. A major problem inColorado is that we do not have a network of permanent seismographs connected to the National Earthquake Information Center (NEIC). We only have two stations, one in Golden and one in Idaho Springs, but they are so close together that they are not much good for triangulating. There is good evidence that NEIC's accuracy for locating the epicenter of an earthquake in Colorado is only ± 10 to 12 miles. Therefore, when it is reported that an earthquake occurred five miles northwest of Glenwood Springs, it may actually have occurred seventeen miles northwest or seven miles southeast of the town. That means valuable time can be lost by emergency personnel in responding to the location of damage or casualties.

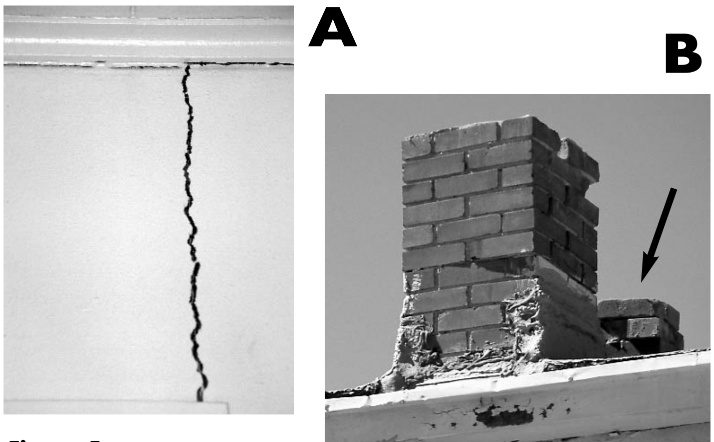

Figure 5.
Examples of damage in Segundo from the M 4.6 earthquake on September 16, 2001.
A) Cracked plasterboard. A number of buildings in Segundo had cracks in exterior and interior walls.
B) Toppled chimney. This chimney was broken off (arrow) by theearthquake and bricks were thrown into the street.
PHOTOS BY V. MATTHEWS

The 2001 Trinidad earthquake swarm emphasizes the problem of locating earthquakes in Colorado. The largest earthquake of the swarm was a magnitude 4.6. Its location was initially reported as two miles south of Trinidad (Figure 6A). However, Trinidad reported no damage. CGS geologists discovered Mercalli Intensity VII damage in Segundo and Valdez, 11–12 miles west of the reported earthquake location, where pictures were thrown off walls, plaster was broken, bottles were emptied out of cabinets, and a chimney was broken and thrown into the street.(Figure 5). The USGS quickly deployed a dense network of portable and temporary seismographs to better understand the earthquakes (Meremonte and others, 2002). Studies using the well-located earthquakes revealed that the largest earthquake was actually under Segundo, rather than near Trinidad. Figure 6 summarizes the difficulty of locating the Trinidad earthquakes.

Fortunately, the USGS has recognized the problem of accurately locating earthquakes in Colorado and is installing two permanent, modern seismographs in the state that will be part of their national network. This is an important step toward better understanding which faults in Colorado are currently generating earthquakes.

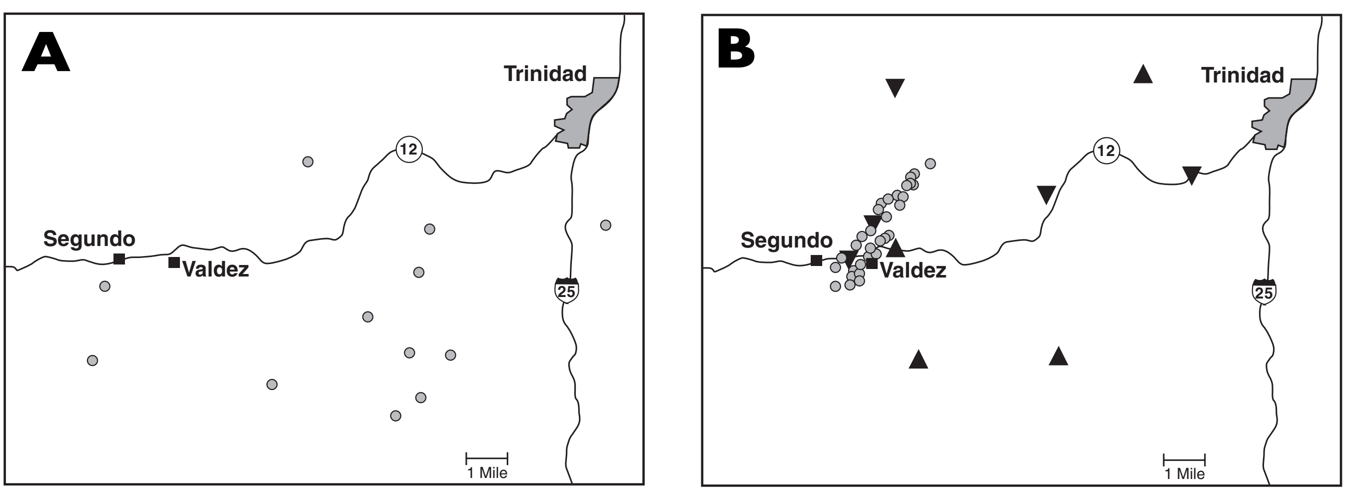

Figure 6. *A) Locations of earthquakes reported by the NEIC prior to installation of the local network. The earthquakes appear to be random, and are scattered over 75 square miles.*

B) Tight northeast-southwest cluster of earthquake locations determined with the local network.

Portable seismographs shown by triangles, earthquakes shown by circles. MODIFIED FROM MEREMONTE AND OTHERS, 2002

Earthquakes Caused by Humans in Colorado

Colorado is the world's premier laboratory for earthquakes induced or triggered by humans. Mine blasts in South Park and Climax in the mid 1960s were large enough to be recorded on the national seismograph network, as were two underground nuclear blasts in 1969 and 1973. But the most famous incidents were three major examples of earthquakes induced by fluid injection. The first was at the Rocky Mountain Arsenal in the 1960s, the second in Rangely Oil Field in the 1970s, and the third in the Paradox Valley in the 1990s. The first of these was a surprise, whereas the others were expected.

Rocky Mountain Arsenal

In the late 1950s, liquid waste was stored in ponds at the U.S. Army's Rocky Mountain Arsenal, famous for its store of nerve gas during the Cold War. In order to alleviate environmental concerns, they decided to inject the liquid into a two-mile deep well. Less than a year after injection began, earthquakes began occurring in the vicinity. Thousands of small earthquakes (in 1967 two earthquakes over magnitude 5.0) were recorded near the Arsenal. The largest caused an estimated $1 million in damage in Commerce City and north Denver.

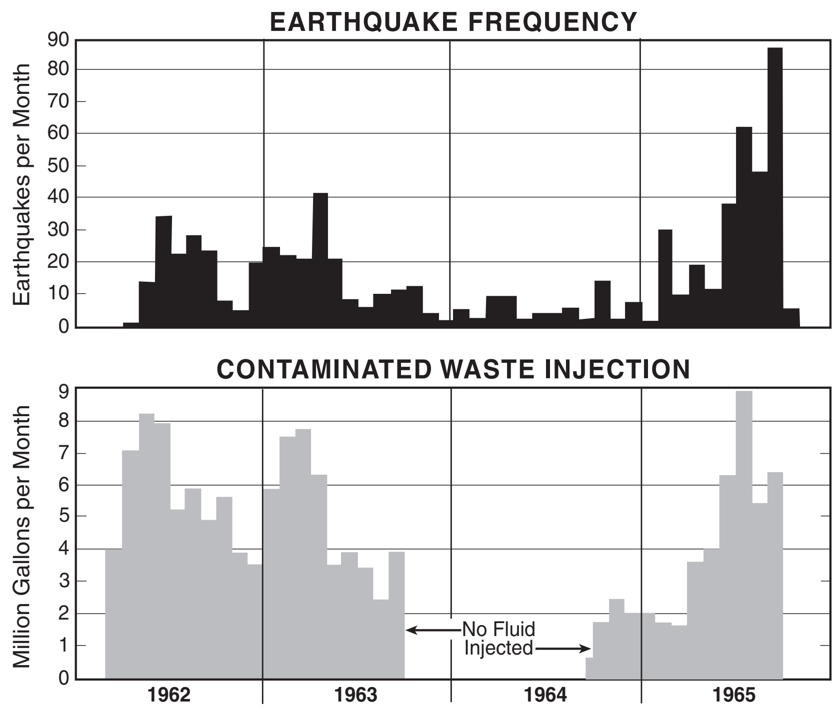

Figure 7. *Charts showing the correlation between Rocky Mountain Arsenal injection volumes and earthquake activity.* MODIFIED FROM EVANS, 1966

After a couple of years of this earthquake activity, a geologist in Denver claimed that the volume of liquid being injected into the Arsenal disposal well correlated with the number of earthquakes occurring in the area; the greater the volume of injected liquid, the higher the number of earthquakes (Figure 7). The Army denied it, many geologists doubted it, and the USGS set out instruments to prove that he was wrong. Instead, they proved that this Denver geologist was correct. Fifteen years later the President's Council on Environmental Quality recognized the geologist, David Evans, with a $50,000 award.

Rangely Oil Field

The USGS was excited about these findings and wondered whether earthquakes could be controlled elsewhere by injecting water. They turned to the giant Rangely oil field in northwest Colorado where minor earthquakes appeared to be associated with water injection used to improve oil recovery. The area of injection was experiencing around 50 minor earthquakes per day. The oil company agreed to let the USGS conduct an experiment to determine whether they could turn earthquakes off and on. They discovered that they could. When the injection ceased, the earthquakes dropped from more than 50 to fewer than ten per day. When they began injection again, the daily number jumped back up to over 50. Over a two-year period, the USGS turned earthquake activity off, on, off, on, and off again–a successful and exciting experiment.

Paradox Valley

The Bureau of Reclamation is diligently working in the Paradox Valley to reduce the amount of salt entering the Dolores River and ultimately the Colorado River. They are currently withdrawing the salty water before it can contaminate the Dolores River. The intercepted salty water is disposed of by a combination of evaporation ponds and injections deep into Earth. The Bureau's scientists expected that this process might trigger earthquakes and thus deployed a network of local seismometers to monitor any activity. They have generated more than 3,000 minor earthquakes since beginning injection in 1995. After experiencing a magnitude 4.3 in May of 2000, they reduced injection to every other month. The result has been no more earthquakes over M 4.0.

Investigating the Cause of the Trinidad Earthquake Swarm

In August and September of 2001, a swarm of earthquakes struck under the towns of Segundo and Valdez, about 12 miles west of Trinidad. That September, two of the earthquakes reached M 4.0 and 4.6. The M 4.6 was felt over 1,600 square miles and caused minor damage in Segundo and Valdez (Figures 5).

In late September of that year, the USGS deployed a local network of 12 portable seismometers in order to precisely locate the earthquakes (Figure 6B). The network detected several hundred small earthquakes. Analysis of 39 of the larger earthquakes showed that they were occurring along a fault plane that started under the town of Segundo and extended to the northeast for 3.75 miles (Figure 6B). The earthquakes appeared to be centered about two to four miles (3–6 km) deep underground (Figure 2). CGS geologists conducted concurrent studies to determine whether the fault is expressed at the surface, which it is.

large number of natural gas wells that were being produced by shallow coal beds in the area. The water produced by coalbed wells is put back into the ground with water disposal wells and a high-volume disposal well that is located near the earthquake swarm. Because Colorado has had earthquakes triggered by water injection wells, it was natural to wonder whether it was happening in Colorado again. A comparison of this well and the Rocky Mountain Arsenal well reveals striking similarities and striking dissimilarities (Table 1):

The comparison in Table 1 shows that there is no clear-cut answer to the question of whether the Trinidad earth quake swarm is similar to the Rocky Mountain Arsenal swarm and was therefore induced by the water injection. Davis and Frohlich (1993) published a test consisting of seven questions to determine whether earthquakes are induced by fluid injection. Unfortunately, their test does not give a definitive answer either. According to the USGS (Meremonte and others, 2002), "The characteristics of the Trinidad sequence summarized by the answers to the [Davis and Frohlich] questions do not rule out the possibility of the Trinidad earthquakes being induced, but neither do they make a strong case for the Trinidad shocks being induced." The earthquakes have diminished in number and strength since September of last year even though the injection volumes remain constant.

***Table 1**. Comparison of characteristics of the Rocky Mountain Arsenal and Trinidad earthquake swarms.*

SIMILARITIES

	Distance of earthquake swarm from bottom hole location of well	Injection volumes during first two years	Maximum magnitude during first two years	Depths of earthquakes	Injection rates	First motion solutions
Trinidad	1–5 kilometers	2,597,210 barrels	4.6	3.6–6.1 km	6000–7000 barrels per day	Normal
Rocky Mountain Arsenal	2–9 kilometers	2,322,381 barrels	4.6	4.5–5.5 km	3175–7000 barrels per day	Normal

DISSIMILARITIES

	Previously recorded earthquakes	Time from start of injection to first earthquake	Injection pressures	Injection formation	Injection depth	Dip of fault	Strike of fault	Length of rupture
Trinidad	1966 (1), 1973 (5), 1992 (2 possible)	68 weeks	Gravity	200–300 foot thick sand	4,123–4,238 ft (1.257–1.292 km)	~70 SE	N45E	5 km
Rocky Mountain Arsenal	None recorded (no good seismic records prior to 1962)	7 weeks	As high as 550 psi	Fractured and faulted crystalline rocks	11,975–12,045 (3.650–3.671 km)	Tenuous SW	NW–SE	15 km

Data from Hermann, and others, 1981; Healy, and others, 1968; Hollister & Weimer, 1968; Evans, 1966.

Earthquakes occurred previously in the general area in 1966 and 1973. In 1966, a magnitude 4.6 earthquake was felt over 15,000 square miles and its location was reported to be northeast of Trinidad. In 1973 a swarm of six earthquakes were felt in the Segundo area. The largest earthquake was M 4.2. Two long-time residents reported that the largest 2001 earthquake was about the same intensity as the largest 1973 earthquake suggesting that they were possibly along the same fault.

A number of people wondered whether there might be a connection between the earthquakes and the

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In Colorado, we struggle with the fact that there is a history of major earthquake activity in the heavily populated Front Range, and limited activity in communities all across the state. The potential for an earthquake in the Front Range is what we identify as "low frequency and high-consequence."

Little public policy has been developed around earthquake potential that is low frequency and high consequence. This fall, the Western State Seismic Policy Council (WSSPC), a group that combines the expertise of Western State Geologists and Emergency Managers, will convene their annual meeting in Colorado to discuss these types of earthquake risks. This group of earthquake-hazard professionals recognizes that no prescribed formula will protect everyone from everything. The need to deal with a variety of hazards issues often appears to be far greater than the resources, and raises difficult questions. In view of competing needs, how should local communities address events of low frequency and high consequence? How can such communities, in dealing with earthquakes for example, compete with other priorities for scarce resources?

If these questions interest you, I suggest you consider attending the WSSPC Annual Meeting in Denver, September 15–17, 2002. For more information, go to the WSSPC website at: www. wsspc.org.

Before any policy can be developed, better earthquake data and more complete studies will be needed. Scientists at CGS are providing such studies. Read on to see what data are available and what studies are underway.

Vicki Cowart, State Geologist

If the earthquakes are purely natural, there is perhaps greater concern for the future than if they are induced. A relationship has been established between the length of a fault and the size of the earthquake it is likely to generate. The detailed studies of the fault under Segundo show that the earthquakes are occurring on a six-kilometer-long fault. A fault of this length is capable of generating a magnitude 5.8 earthquake (Wells and Coopersmith, 1994). FEMA's HAZUS99 model predicts $15 million in damage if an earthquake of that size occurred on this fault.

Why Has Colorado's Earthquake Situation Been Ignored or Downplayed for So Long?

Many people in and outside of the state are surprised to learn that Colorado has recorded more than 500 earthquakes, one of which was M 6.6. In attempting to assess the earthquake potential in Colorado, CGS researchers have identified a number of factors that probably work in concert with each other to make earthquakes in Colorado a lower priority in people's minds than they should be.

- Colorado's faults were long considered to be Laramide or older in age, with no movement during the past 40 million years.
- Quaternary faults were not recognized in the state prior to 1970.
- The abundance of induced earthquakes at the Rocky Mountain Arsenal and Rangely drew attention away from the natural earthquakes (Figure 4).
- The largest earthquake in Colorado was not definitively located until 1986.
- Microseismic events were claimed not to cluster or be linked with specific faults.
- Paleoseismic discoveries in areas such as California, Washington, South Carolina, and New Madrid drew attention and resources away from the findings in Colorado.

Experience shows that the more we look for evidence of young fault activity in Colorado, the more we find. In 1970, Colorado's catalogue of

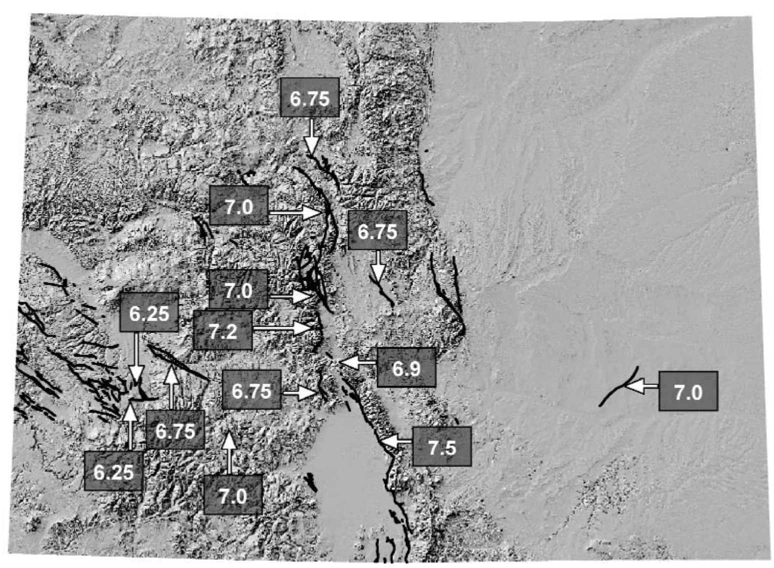

Figure 8. *Maximum credible earthquakes. The Quaternary faults on this map have been studied and assigned a maximum credible earthquake based on the length of the fault, the age of latest movement, and the recurrence interval for past earthquakes.*

Quaternary faults totaled only eight (Scott, 1970). Our 1998 catalogue includes 92 Quaternary faults (Widmann, and others, 1998). Many parts of Colorado have not received the intense search for past earthquake activity that other states such as South Carolina, Missouri, Illinois, and Tennessee have received.

The map in Figure 8 is a compilation of faults in Colorado that have been studied by geotechnical engineers and assigned a "maximum credible earthquake." It is sobering to see how strong and widespread the potential earthquakes are.

What is the Colorado Geological Survey Doing About Earthquakes?

CGS geologists are involved in a variety of aspects of earthquake hazard research in Colorado. For several decades CGS has conducted limited field studies, monitored the research of others, sponsored symposia, and gathered known information on earthquakes and faulting in the state. Our activities are coordinated with a variety of other groups including the Western States Seismic Policy Council (WSSSPC), the United States Geological Survey (USGS), the Colorado Office of Emergency Management (COEM), the Federal Emergency Management Agency (FEMA), and the National Earthquake Hazard Reduction Program (NEHRP)

Western States Seismic Policy Council (WSSSPC)

CGS is an active member of WSSPC, an organization made up of geoscientists and emergency managers from 13 western states, three U.S. territories, and two Canadian provinces. The members of this organization are searching for better ways to prepare for, and respond to, earthquakes. They develop policies and share ideas, experiences, and resources. CGS and the Colorado OEM are co-hosting the 2002 Annual Meeting of WSSPC in Denver. The Denver meeting's theme is appropriate for Colorado: how do communities deal with low-frequency but high-consequence earthquakes? For more information visit their website at http://www.wsspc.org.

CGS/USGS Cooperative Efforts

The USGS has two important groups headquartered in Golden, the National Earthquake Information Center (NEIC) and the National Seismic Hazards Mapping Project. Cooperation and coordination between CGS and these two groups is excellent. This spring USGS and CGS personnel will convene in the San Luis Valley to discuss earthquake hazards in Colorado, and to identify high-priority areas for further earthquake hazard research in the state. For more information on these two groups visit their websites at: http://neic.usgs.gov and http://geohazards.cr.usgs.gov/eq/ index.html.

Colorado Earthquake Hazards Publication

CGS provided much of the scientific data for the Colorado Office of Emergency Management's (COEM) publication, *Colorado Earthquake Hazards*. The publication contains a map showing the location of Colorado's historical earthquakes and the 92 known faults that have moved during the Quaternary Period. Information on preparing for an earthquake and the Modified Mercalli Intensity Scale is included. A free copy of this publication may be obtained from CGS or COEM. For more information visit COEM's website at: http://www.dlg.oem2.state.co.us/oem/Publications/publications.htm.

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Colorado Natural Hazards Mitigation Council—Geologic Hazards Committee

CGS geoscientists meet regularly with members of the Earthquake Subcommittee of the Geologic Hazards Committee. The group is composed of structural engineers, seismologists, consultants, geoscientists, insurers, and emergency managers who are interested in reducing the earthquake risk in Colorado. The members meet bi-monthly to consider recent earthquake research and its impact on Colorado. In late 1999, the Earthquake Subcommittee concluded a two-year effort to produce a consensus fact sheet on earthquakes and seismicity in Colorado. This fact sheet was incorporated into the publication Colorado Earthquake Hazards. More information is located on the subcommittee's website: http://geosurvey.state.co.us/pubs/equake/subcommittee/subcommittee.htm.

CGS/FEMA Cooperative Efforts

CGS also works closely with Federal Emergency Management Agency (FEMA) personnel. Recently FEMA and CGS geoscientists collaborated on a successful grant proposal to study earthquake hazards in Colorado. FEMA recently released a report on nationwide Annualized Earthquake Losses using their disaster model HAZUS99. Their study estimates that Colorado can expect to suffer $5.8 million in losses from earthquakes on an annualized basis. FEMA's website is http://www.fema.gov/.

CGS Earthquake Hazard Research

CGS geoscientists study earthquake hazards through two grants funded by the National Earthquake Hazard Reduction Program (NEHRP) and through the CGS Critical Hazards Program, funded by severance taxes on petroleum and mineral production. We also study earthquake hazards through our geologic mapping program funded by the USGS STATEMAP program and severance taxes.

Bob Kirkham received a NEHRP grant to study young faulting in the Williams Fork valley. The area is located 10–15 miles north of Dillon Reservoir where young faults have the highest reported slip rate in Colorado.

Vince Matthews and Matt Morgan received a NEHRP grant to study young faulting in the northern Front Range. This is a collaborative study with Jim McCalpin of GEO-HAZ Consulting. Matthews and Morgan will conduct a regional study of faulting in the Front Range, whereas McCalpin is doing a localized study in the Estes Park area. Both efforts are directed toward finding further evidence of Quaternary faulting in the Front Range, as well as the possible source for the M6.6 earthquake near Estes Park in 1882.

Mappers in CGS' 1:24,000 geologic mapping program are constantly on alert for evidence of young faulting. Last summer, new Quaternary faults were mapped in Costilla County and a new Holocene fault was mapped in Summit County.

CGS Earthquake Reference Collection

Through the years, CGS has been gathering information on earthquakes and faults in Colorado. We maintain an Earthquake Reference Collection that includes many hard-to-find articles and reports on earthquakes in Colorado. Researchers may use this collection by appointment. Index to the collection is online at http://geosurvey.state.co.us/pubs/equake/erc.htm.

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This Issue

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CGS Earthquake-Related Publications

For several decades CGS has been issuing publications related to earthquake and fault studies in Colorado. CGS Earthquake-Related Publications still in print are:

B 52, Colorado Earthquake Information, 1867–1996
By R.M. Kirkham and William P. Rogers, 2000
A report on historic seismicity, potentially active faults, evidence from Quaternary tectonism, and land-use implications. Runs on both Windows and Macintosh platforms. Award-winning CD-ROM. **$15.00**

IS 23, Results of a Search for Felt Reports for Selected Colorado Earthquakes
By S. Oaks and R.M. Kirkham, 1986
Felt reports for several widely reported earthquakes in the pre-instrumental time. Primary documentation emphasized; newspapers also checked for time hear events and possible aftershock. 89 pages. **$6.00**

OF 98-08, Preliminary Quaternary Fault and Fold Map and Database of Colorado
By B.L. Widmann, R.M. Kirkham, and W.P. Rogers, 1999
Text and CD-ROM. Summary information from published and unpublished reports on the 92 faults documented as having moved during recent geologic time (Quaternary Period). Provides essential input to the engineering design of dams, infrastructure, and other major facilities. CD-ROM contains Quaternary fault and fold traces on 1:250,000 scale base maps in Adobe Acrobat (reader included). Text and 1:500,000 scale map may be purchased without CD-ROM for **$35.00**
CD-ROM and Text **$50.00**

SP 28, Contributions to Colorado Seismicity and Tectonics: A 1986 Update
By W.P. Rogers and D.B. Collins, eds., 1986
A collection of 23 recent short papers and reports on seismicity and tectonics in Colorado by individuals and organizations doing project or research work directly relevant to Colorado. 301 pages. 81 figures. 8 tables. **$15.00**

Colorado Earthquake Hazards
By Colorado Office of Emergency Management, 1999
A map of earthquakes and related hazards in Colorado. Includes earthquake fact sheet, list of largest earthquakes, personal earthquake preparedness, quaternary faults, and Modified Mercalli Intensity Scale. **Free**

Earthquake Building Codes

The International Building Code contains provisions for designing structures to withstand the expected shaking from earthquakes. These codes prescribe a certain level of earthquake resistance for different parts of Colorado based on earthquake hazard mapping by the USGS. However, in order to be at all beneficial, the earthquake provisions of the code must be adopted by local governments and they must then be enforced. Neither is uniformly occurring throughout the state.

Earthquake Insurance in Colorado

Most homeowner insurance policies in Colorado do not cover losses incurred as a result of earthquakes. Most insurance companies will sell homeowners in Colorado a rider that provides some protection in case of damage from an earthquake. However, a homeowner should understand a policy thoroughly before purchasing it. It is common to see earthquake insurance riders that have a deductible equal to 15 percent of the value of your house. Under those circumstances, if your house is worth more than $250,000, then your house would have to suffer more than $37,500 in damage before you would collect anything.

What Can I Do to Prepare for an Earthquake in Colorado?

Learn what to do in an earthquake and how to protect your family with COEM's publication *Colorado Earthquake Hazards*. You can request a free copy of this publication from CGS or COEM.

Preparation for an earthquake involves common sense and is much the same as general preparation for other natural hazards or for acts of terrorism. Are you prepared for disruption of power, water and other critical services? In an earthquake, falling objects would be one of your biggest concerns and it is the cheapest hazard to prevent. Don't put pots, pictures, or other heavy objects on a shelf over your bed where they could fall on your head. Is your gas water heater strapped down so that it doesn't fall over and start a fire? Fortunately, wood frame homes withstand the shaking of earthquakes fairly well. There is little concern about your wood-frame home collapsing unless it is affected by a secondary effect such as an earthquake-triggered landslide, rockfall, or dam failure. Most homeowners in California suffer only minor structural damage, but they still have major messes to clean up!

(References follow on page 12)

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